SCIENCE FOR GLASS PRODUCTION

UDC 666.11:629.7

STUDY OF DEFECTS IN QUARTZ GLASS WITH THE ACTION OF HIGH-VELOCITY MICROPARTICLES ON PORT-HOLES

V. F. Solinov[1]

Translated from *Steklo i Keramika*, No. 8, pp. 9 – 12, August, 2010.

The operation of any space craft involves a danger of random collisions with so-called space junk and bombardment by different microparticles (meteorites). Traces of impacts of microparticles of meteorites in the form of damage defects on the surface of the quartz glass of port-holes have been found on the MIR space station and International Space Station (ISS). Research to find criteria to assess the residual strength of quartz glass is being conducted to assess the danger of these defects. Five subzones of damage have been found in the zone of a defect. Analysis of these subzones shows that the dangerous subzones — stress concentrators — are the 3rd and 4th subzones.
A method has been found for evaluating the impact energy of microparticles according to the morphology of defects. The impact energy has been determined for a defect with diameters 2.5 mm, obtained on the No. 13 port-hole of the ISS.

Key words: quartz glass, space port-holes, stress concentrators, residual strength of glass.

The operation of any space craft is subject to the danger of random collisions with so-called space junk and bombardment by cosmic microparticles of asteroid origin, collisions with which can give rise to undesirable problems associated with life-support for the ship and its crew. For this reason close attention has been devoted from the very beginning of the space era to questions concerning the survivability of space crafts, including the integrity of optical port-holes.

Before the MIR space ship, which operated for about 15 years, was sunk, the surfaces of all port-holes were photographed. It was found that surface damage to quartz glass with defect diameters to 13 mm is present in almost all port-holes as a result of the impacts of cosmic particles.

Traces of impacts of meteoritic microparticles on the 13-m port-hole were also found during the operation of the International Space Station (ISS) (Fig. 1). A 2.5 mm in diameter defect due to damage to the glass surface can be seen in a photograph of the port-hole. Is such a defect dangerous for further operation of the glass?

An international working group comprised of specialists from the Scientific – Research Institute for Technical Glass, the S. P. Korolev Rocket – Space Corporation "Énergiya," the Federal State Unified Enterprise M. V. Khrunichev Center, and representatives of NASA. Research is being conducted in the following directions:

1. Development of methods for examining the glass in ISS port-holes during operation;
2. Development and creation of instruments for investigating defects on port-hole glass during operation;
3. Examination of the glass of ISS port-holes;
4. Analysis and systematization of defects in port-hole glass during operation;
5. Development of a mathematical model of the interaction of high-velocity particles with the surface of brittle materials for the purpose of evaluating the stresses arising in the port-hole glass;
6. Development of methods and equipment for reproducing the defects in the glass under laboratory conditions;
7. Investigation of the effect of defects on the longevity of glass and port-hole reliability;
8. Investigation of the effect of defects on the optical characteristics of port-holes;
9. Experimental work on reproducing defects on glass under laboratory conditions;
10. Development of manuals on admissible defects on glasses to ensure the safety of port-holes;
11. Development of measures (with greater than admissible appearance of defects on glass) to ensure safe operation of the ISS.

[1] Scientific – Research Institute of Technical Glass JSC, Moscow, Russia (e-mail: vfsolinov@bk.ru).

0361-7610/10/0708-0234

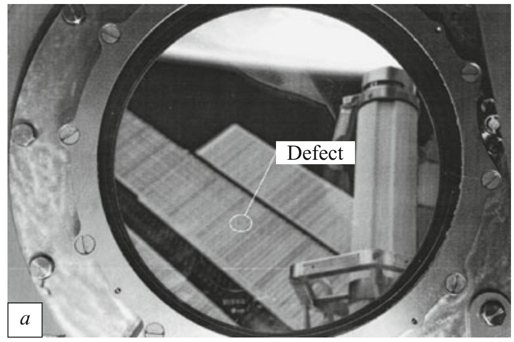
The work group meets every year in Russia and USA. The results of the research conducted by both countries are discussed at these meetings.

The research is divided into two directions:

– analysis of the state of port-holes in space;

– simulation of impacts of cosmic particles on Earth and investigation of the residual strength of the glass.

In space, cosmonauts continually monitor the state of port-holes by photographing them from the outside and inside the station to look for the appearance of any kind of defects. These photographs are transmitted to Earth for investigation.



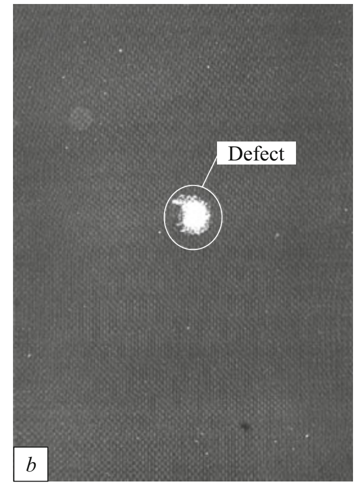


Fig. 1. Port-hole No. 13 on ISS: *a*) general view; *b*) 2.5 mm defect on quartz glass of the illuminator.

The objective of ground-based tests is to reproduce the "space defects" on samples and to investigate these defects in detail. Special vacuum high-velocity guns (Fig. 2) were designed and built for this purpose; these guns make it possible to simulate the impact of microparticles with mass from tenths to 10 mg and greater by small aluminum or glass spheres to velocity 6.5 – 7.5 km/sec. Targets consisted of $100 \times 100 \times 5$ mm^3 samples of silicate and quartz glass, 250 mm in diameter and 15 mm thick. Table 1 gives a matrix of nine samples for tests.

In the course of the tests it was found that for very strong impacts five subzones of different types of surface damage to the glass are observed (Fig. 3).

Zones of fracture of the samples in a collision (view from above and side) are shown in the photographs (Fig. 4). Analysis of the figures shows that as the impact energy increases, the morphology of the fracture zone increases and new defects appear (subzones).

Probably, not all subzones are sources of dangerous cracks and under extreme conditions are responsible for processes which can give rise to fracturing of the glass. For this reason, the investigations focused on the interrelation of frac-

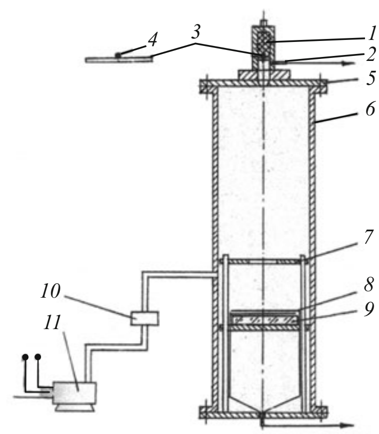


Fig. 2. Vacuum gun for simulating the impact of high-velocity microparticles: *1*) charge; *2*) sensor; *3*) membrane; *4*) projectile; *5*) cover; *6*) case; *7*) cut-off; *8*) connecting circuit; *9*) glass sample; *10*) valve; *11*) vacuum pump.

TABLE 1. Matrix of Samples for Studies

Sample No.	Sample thickness, mm	Particle diameter, mm	Impact velocity, km/sec	Impact angle, deg
1	5.05	0.20	6.8 ± 0.2	0
2	5.08	0.20	6.8 ± 0.2	45
3	5.09	0.20	6.8 ± 0.2	60
4	4.86	0.10	6.8 ± 0.2	0
5	4.84	0.10	6.8 ± 0.2	45
6	5.05	0.10	6.8 ± 0.2	60
7	5.06	0.07	6.8 ± 0.2	0
8	5.19	0.07	6.8 ± 0.2	45
9	4.95	0.07	6.8 ± 0.2	60

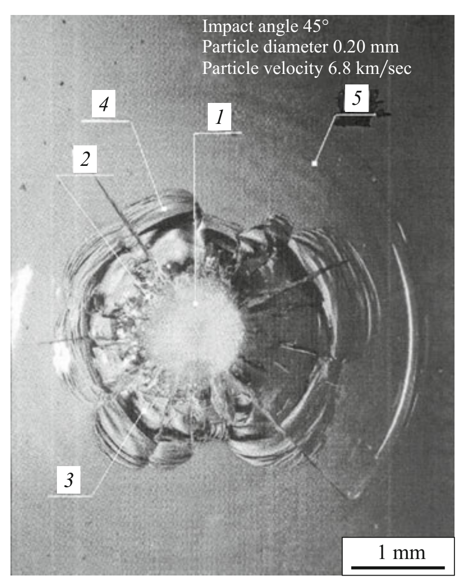


Fig. 3. Five subzones of damage in a defect: *1*) zone of primary contact with a particle, ejection of fragments; *2*) zone of fine cracking of the glass; *3*) zone of internal convex-type chippings; *4*) zone of internal concave-type chippings; *5*) surface chipping.

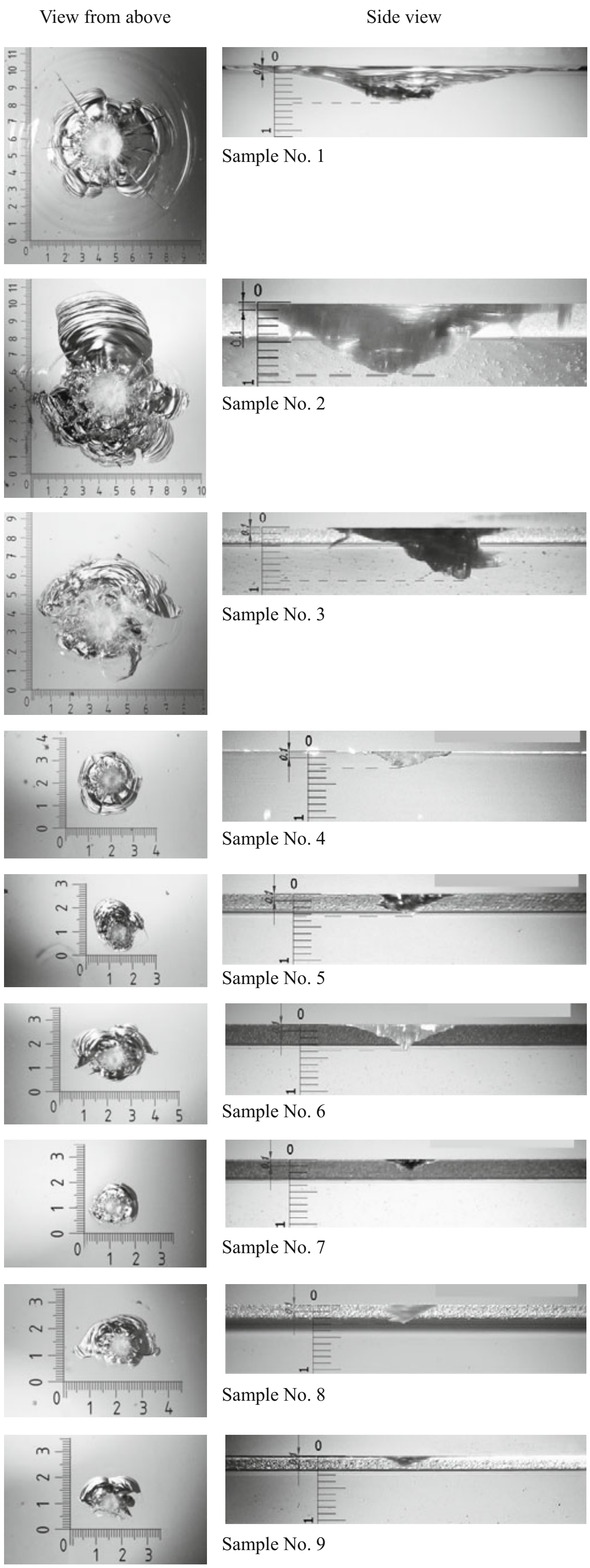


Fig. 4. Zones of fracture of samples.

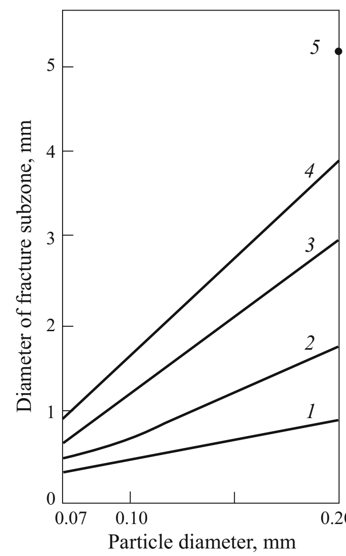


Fig. 5. Curves showing the dependence of the diameters of five fracture subzones in quartz glass on the impact of microparticles with different diameters.

ture subzones with crack formation during the operation of port-holes.

Figure 5 shows the dependence of the diameter of the fracture subzones in quartz glass on the impact of microparticles with different diameter. It is evident that the size of the fracture subzones increases practically in direct proportion to the increase of the particle diameter.

The proven dependences enable us to determine the impact energy of the cosmic microparticles with the appearance of any defect on port-holes during ISS operation by studying the morphology of the entire fracture zone and the number of fracture subzones.

So, by analyzing a defect with diameter 2.5 mm in the No. 13 port-hole on ISS we can say that three fracture subzones are visible in this location, and this shows that the impact carried energy corresponding to a particle with diameter of the order of 0.17 mm and collision velocity $v = 6.8$ km/sec.

Data on the impact energy are very important for calculating the residual strength of the glass.

Figure 6 shows the dependences of the depth of defects in collisions occurring at different angles. It is evident that the fracture depth for an oblique collision is greater than for a vertical collision and, especially interesting, the depth of the defect at an impact angle 45° is greater than under 60°. At the same time the greatest diameter of the fracture zone is observed for a collision at zero impact angle. Apparently, these data show that for residual strength of the glass it is inclined collisions that are most dangerous. How can this be? Only tests for the residual strength of glass could give an answer to this question. Data obtained on the strength of samples by the centro-symmetric bending method are presented in Table 2.

Figure 7 shows the dependence of the glass strength on microparticle diameter. It is evident that even negligible

TABLE 2. Results of Measurements of the Strength of Experimental Specimens of Quartz Glass by the Centro-Symmetric Bending Method

Specimen No.*	Thickness, mm	Load, N	Maximum strength, MPa
1	5.05		22
2	5.08	1814	30
3	5.09	1520	25
4	4.86	1373	25
5	4.84	2059	37
6	5.05	2206	37
7	5.06	1618	27
8	5.19	2598	41
9	4.95	2010	35

* See Table 1.

damage of the glass surface (specimen 8) sharply affects the loss of strength of the glass. The data obtained on the strength for samples with particle collision angle 45° were unexpected. Even though the defects show the maximum depth the specimens have the highest residual strength.

This shows that the depth of a defect is not a criterion for evaluating the degree of danger which a defect poses for port-holes during the latter's operation.

To determine the residual strength of the specimens it was proposed that the network of cracks be recorded after fracture and character of their development be studied. As a result it was found and is clearly seen that for practically all specimens when the center of the cracks formed coincides with the center of a defect (Fig. 8) the sources of the crack development are the ends of the edges of chip surfaces of the third and fourth subzones, which completely coincide with the network of cracks. Thus it has been established that in the case of impact by microparticles and observation in the fracture zone the third and fourth subzones we are dealing with stress concentrator that pose a danger for operation. For this reason, first and foremost, it is necessary to perform research work to evaluate the residual strength of glasses with defect in port-holes. Since third subzone has been found in a defect in the No. 13 port-hole on ISS, to ensure safe operation a stopper was delivered to the station and will be installed if the defect becomes larger. In addition, the search for criteria for evaluating the residual (permanent) strength of glass in the presence of a defect will continue.

CONCLUSIONS

As the investigation have shown, the depth and character of the fracture of defects formed in the quartz glass of space port-holes bombarded by high-velocity particles are not characteristic of defects which appear during operation under ground-based conditions and required careful study of the residual strength of the glass for defect depths ≥ 1 mm.

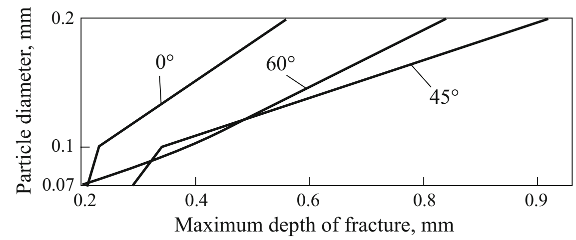


Fig. 6. Depth of a defect in glass with microparticles striking a glass surface at different angles.

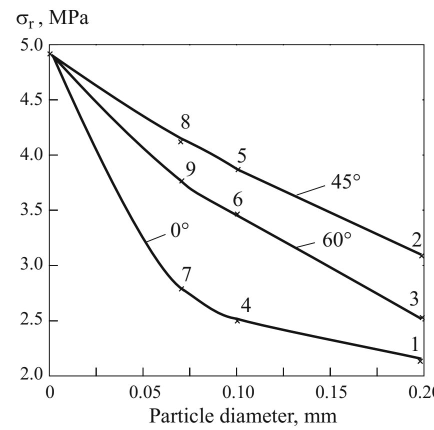


Fig. 7. Residual strength of glass σ_r versus the diameter of the particles for different angles of impact against a glass surface.

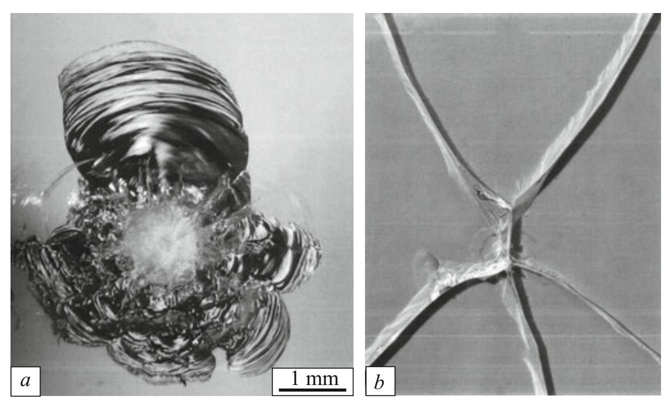


Fig. 8. View of a defect on glass specimen No. 2, (*a*) and networks of cracks (*b*) after quartz glass was tested for fracture.

For sufficiently strong impacts, five subzones of fracture have been found in the fracture zone of a defect.

It was found that the ends between chipping surfaces of the third and fourth subzones are locations of dangerous stress concentration.

The fracture depth is not a criterion for evaluating the residual strength.

The formation of any defect from an impact by a high-velocity cosmic particle, even one with very small mass (energy), seriously lowers the residual strength of the quartz glass of a port-hole.